## Design Study Report

# Full-Scale Design Studies of Ballast Water Treatment Systems

Prepared for

**Great Lakes Ballast Technology Demonstration Project**

**Northeast-Midwest Institute**
**Washington, DC**

**and the**

**Lake Carriers' Association**

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**G**losten-**H**erbert
**H**yde Marine

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## APPENDICES (bound separately – dated 13 November 2001)

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# ABSTRACT

The Great Lakes Ballast Technology Demonstration Project recently funded three 6-month, full-scale design studies of promising ballast water treatment systems. The intent of each study is to fully develop, for a specified “target” vessel, the contract design and life-cycle cost of a reliable, optimized flow-through, on-board treatment system that effectively removes living organisms from the ship’s ballast water before it is discharged into an ecosystem other than its original source. The authors address two of these three studies, selecting two different kinds of target vessels. These ships represent classes of vessels typically involved in ballast water discharge in the ports and waterways of the U.S. West Coast, Hawaii and Alaska. This is one of the first efforts devoted to developing contract design level technical solutions, quantifying life-cycle costs and assessing actual vessel operational impacts on effective ecosystem maintenance.

# 1. INTRODUCTION

Introduction of nonindigenous species to new environments is one of the greatest threats to the world’s coastal waters. Ballast water is a major contributor to the transfer of harmful organisms and pathogens. Potential economic impacts and impacts on human health and the ecology are very significant and cannot be ignored.

A substantial amount of scientific study has been devoted to the problem of invading species that are carried in ships’ ballast water. The solutions to the problem are simple in concept, but complex in execution. These solutions are illustrated in Figure 1 below.

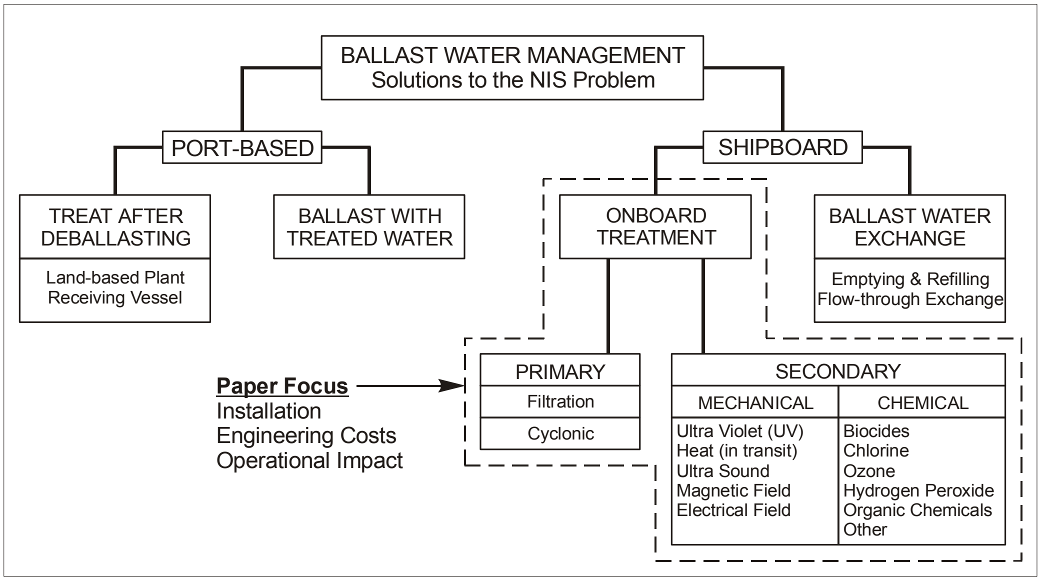

**Figure 1. Paper Focus (Chart Originated in Reference [1])**

Most maritime professionals agree that ballast water exchange, which is currently the only officially recommended method for limiting the transfer of organisms in ballast water, has many limitations and is not the long-term answer. Effective ballast water treatment methods must therefore, be developed and their efficacy established. The installation engineering of these systems, as applied to specific ships, is the focus of this project report.

The Great Lakes Ballast Technology Demonstration Project (GLBTDP) [2, 3], led by the Northeast Midwest Institute and the Lake Carriers' Association, has made an important step in the process of moving toward control of invasive species. It seeks operationally sound and biologically effective ballast water treatment solutions, going from the science and study stage to the engineering stage, by applying the science to specific, full-scale installations – with the objective of assessing engineering practicalities and cost.

GLBTDP contracted with Herbert Engineering and The Glosten Associates – two Naval Architecture and Marine Engineering design firms experienced in conducting design studies, developing contract plans, and preparing packages for regulatory review and approval. Hyde Marine supported the studies with equipment definition. Ship owners Polar Tankers, Inc., (previously ARCO Marine, Inc.) and Matson Navigation supported the effort at no cost. These ship owners have a real interest in installing treatment systems in their vessels. Addressing owner preferences was a very important part of the study.

Two design studies addressed the application of specifically selected systems to target vessels by retrofitting ballast water treatment systems into these existing ships. It is anticipated that designing treatment systems for new construction will be significantly less expensive than the retrofits presented in this study.

**Table 1. Summary of Studies**

| **Target Vessel** | | | | **Treatment System** | |
|---|---|---|---|---|---|
| **Ship Name, Type and Owner** | **Ballast Rate** | **Ballast Capacity** | **Route** | **Primary Treatment** | **Secondary Treatment** |
| *M/V Polar Endeavour* (Millennium Class), Polar Tankers, Inc. | Two (2) @ 2,860 m$^3$/hr (12,600 gpm); (main system) | 60,700 m$^3$ | TAPS Trade – Alaska & U.S. West Coast | Cyclonic Separator* | Ultraviolet Radiation* |
| *M/V R. J. Pfeiffer* 2,420 TEU Containership, Matson Navigation | Two (2) @; 350 m$^3$/hr. (1540 gpm); (Only one pump is used for ballasting) | 14,600 m$^3$ | U.S. West Coast and Hawaii | 1) Cyclonic Separator<br>2) Filters with auto backflush (alternate) | Ultraviolet Radiation |
| *Treatment System for *Polar Endeavour* includes a chemical treatment option. | | | | | |

Although generic treatment system types were selected for the study, specific equipment was identified and integrated into the ship systems' designs, and firm equipment prices were used in the cost estimates. System performance data presented in this paper are based on manufacturer claims and some recent full scale tests.

Table 1 briefly describes the primary treatment systems and targeted vessels selected for each of the two studies. Complete details of the treatment systems and vessels can be found in the following sections.

# 2. TREATMENT SYSTEM REQUIREMENTS

## 2.1 Overview

As stated earlier, the intent of each study is to perform the actual design and engineering for a practical and reliable on-board treatment system that “effectively” removes living organisms, bacteria and viruses from shipboard ballast water. However, identifying systems requirements that achieve this goal are somewhat complicated because the biology of invasive species is a developing science and no current efficacy standards exist. Therefore, the requirements must be framed to answer the following questions:

1) What does “effectively removed” really mean and does the selected system provide the desired kill/removal rate while producing no other environmental hazards?
2) Can the selected system be manufactured, installed and operated in a practical and economically sensible manner?

The recent Globallast Workshop [4] provided a more specific outline of the primary design requirements:

For the biological considerations:

- It must be environmentally acceptable (not causing more or greater environmental impacts than it solves).
- It must be biologically effective (in terms of removing, killing or otherwise rendering inactive aquatic organisms and pathogens found in ballast water).

For the system engineering considerations:

- It must be safe (in terms of the ship and its crew).
- It must be practicable (compatible with ship design and operations).
- It must be cost effective (economical).

The work reported herein does not try to address all of the biological issues and questions. Rather, the critical questions that must be asked when selecting and designing a system installation are identified, and then the best and latest information from the current body of knowledge is used to answer those questions. System engineering can then proceed on good candidate technologies to determine if they meet the shipboard practicality requirements.

## 2.2 Requirements for Biological Effectiveness and Environmental Concerns

The only current metric regarding biological efficacy is ballast water exchange. The commonly held view is that any new system should be "at least as effective as ballast water exchange." Exchange involves the replacement of near shore or coastal water with open-ocean water during a voyage. This reduces the density in ballast tanks of coastal organisms that may be able to establish themselves in a recipient port, and replaces them with deep ocean organisms that have a lower probability of survival in the near shore ecosystems.

However, the exchange is never 100% complete. There will invariably be some residual density of coastal organisms surviving when the ballast water is discharged. The current "best estimate" of the effectiveness of exchange (when it can actually be implemented) is that there is a 95% volumetric exchange of ballast water. For some ships the volumetric exchange can be considerably less than 95% complete, because of incomplete mixing due to the geometry and structure with the ballast tank and the locations of the inlet piping and discharge opening. This does not necessarily equate to 95% reduction of the target organisms within the ballast tanks, however. When considering more rigorous metrics for efficacy, the Globallast attendees [4] actually state "*…it is not appropriate to use equivalency with volumetric exchange as a biological effectiveness standard.*"

It is also generally agreed that 100% biological effectiveness of ballast water treatment is not achievable for all aquatic organisms and pathogens with the best currently available technology. So, the question of an appropriate design target efficacy cannot yet be clearly elucidated and is the subject of ongoing research and debate.

One deadline for the efficacy standard debate is the U.S. government action plan [5], which directs the U.S. Coast Guard to issue standards by January 2002. In addition, the Globallast [4] workshops were held in preparation for IMO MEPC 46. They focused on the efficacy standards issue with the objective "To develop a range of possible standards, and in particular *effectiveness standards*, for the evaluation and approval of new BWT systems." It is useful to note that the workshop concluded that:

- these standards should be developed using risk assessment/risk management methods and require performance based compliance,
- approval tests should consider water quality (salinity, turbidity, temperature, etc.),
- there should be a single, global, primary biological effectiveness standard, but it may be appropriate to develop additional standards for specific geographical regions, different taxonomic groups, different vessels, etc.,

For this report then, the de facto design targets are the capabilities of the most promising treatment system technologies as determined in recent industry testing. The actual efficacy will await rigorous on-board testing of actual installations. In this context, the following general biological system requirements and relevant considerations are presented.

## Kill/Removal Rates

The target organisms include phytoplankton, macro-algae, zooplankton (vertebrates and hard-shelled/soft-shelled/soft-bodied invertebrates), bacteria and viruses. Important efficacy measures are initial kill/removal rate and delayed kill/removal rate or inactivation.

The final biological performance of any system will depend not only on its ability to kill or render inactive the target organisms, but also on [6]:

- whether treatment is performed on intake and/or discharge,
- the length of retention on board (regrowth potential and delayed die-off),
- likelihood of cross-contamination (residual organisms) from piping and tanks increasing chances for regrowth, and
- regrowth potential on discharge if kill/removal rates are not 100%.

It is especially important to note that target kill/removal rates should at least be based on the ballast water at discharge because of the regrowth potential of the rapidly reproducing organisms. It has been shown in tests that some organisms can be subjected to treatment and then regrow to be measured in greater numbers after being retained on board in dark ballast tanks [6].

One of the biological effectiveness standards proposed by the Globallast workshop specifies “at least a 95% removal, kill or inactivation” of representative taxonomic groups. These groups include the vertebrates, invertebrates, most phytoplankton and macro algae. Bacteria and viruses (pathogens), dinoflagellate cysts and similar organisms are excluded because it “will be extremely difficult to achieve the target rate with the best currently available technology.” Instead, the standard requires vendors of new ballast water treatment technologies to report data on removal, kill or inactivation of these species, allowing the standard to be revised and updated as data accumulate and technology improves over time.

The systems presented in the current studies are in line with this reasoning and are close to performing near the proposed standard. For information and to the extent possible, test results for the ‘difficult-to-kill’ species are reported with the system descriptions provided below.

## Size Targets for Organisms

Removal of organisms from the ballast water (in addition to kill or inactivation) is a vital component of any treatment system. Any system will have at least a grating over the sea suction to keep out large animals. Beyond that, a system may be specifically designed to remove organisms of a certain size and above. Testing of filtration systems [3] has been carried out to determine practical operational limitations of filters of 25, 50 and 100 micron size. Their biological effectiveness was also reported.

A second biological effectiveness standard proposed by the Globallast workshop, specifies nearly 100% removal of all organisms in select size ranges. The first is “>100 microns.” Phasing in over some years is a requirement for removal of organisms greater than 50 and then

10 microns – the idea being that the greater than 100 micron size range may be achievable with current technology and would permit some valuable system development to begin soon. More restrictive requirements would be added as technology progressed.

The systems presented in the current studies refer to the 100 micron target for filtration systems. Particle size removal for other systems are reported when test data are available.

### Turbidity, Suspended Solid Limits

The turbidity or amount of suspended solids in the ballast water is one of the water quality issues that must be addressed when testing/evaluating treatment systems. For example, the effectiveness of UV treatments has been shown to decrease as turbidity increases. The turbidity, in this case, affects the ability to transmit the UV light (transmissivity). Kill/removal rates are dependent on a certain light intensity reaching the target organism.

To reduce turbidity, particles down to the 6 to 12 micron range must be removed. If a system cannot reduce or control turbidity, its design must account for the ambient turbidity likely to be encountered. Alternatively, operational procedures may have to be designed to take on ballast water in areas without high turbidity (such as deeper water or from high sea suctions not too close to the sea floor).

### Tertiary Effects on Environment

The Globallast workshops [4] identified "environmental acceptability" as one of the primary criteria for any ballast water treatment system. Basically, any system should not cause more or greater environmental problems than it solves. This may seem obvious but it is essential that it be considered carefully because tertiary effects are sometimes very difficult to ascertain. Such side effects may include lasting impacts of chemicals, or faster breeding of stronger and more resistant strains of bacteria. This latter example, regrowth of the survivors of initial treatment during holding of the ballast water or after discharge, could be a problem for any treatment system that is not 100% effective.

## 2.3 Ship and Owner Requirements

The selection requirements placed on any treatment system by the ship and its owner/managers are much more easily identified. They are essentially no different than any other shipboard system in this regard, and must meet the practical installation, operational and economic constraints imposed by the shipboard environment.

### Meet the Demands of the Shipboard Marine Environment

Vibrations, accelerations, ship motions and the salt water atmosphere, are all key design parameters for any equipment placed on board a vessel. Many systems produced for shoreside use have not been designed to operate in this marine environment.

Therefore, when selecting system components, service history on board ships is very helpful. Experience in other industries or applications are interesting, but are not always useful in assessing the robustness for shipboard use or its regular maintenance requirements/procedures. Also, other industries may be processing water with different characteristics (salinity, suspended solids, etc.) that may affect basic system performance. For example, filters that work well for fisheries or offshore rigs, where intakes can be carefully placed to avoid suspended solids, may not perform to ratings when ships' ballast water is taken in the silty waters of a harbor. Flow rates, pressure drops, cleaning and maintenance requirements may be quite different.

### Minimize Operational Changes to the Vessel's Existing Ballast Management Processes

Vessels are initially designed with ballasting capabilities that match their intended service and voyage profile. This includes where and when they can take ballast and the time for the ballast intake and discharge process. A treatment system should ideally fit within the current or planned ballast sequence and timing. Ballast exchange is an example of a solution that requires a complete change in ballast management operations. A treatment solution should try to avoid much of this disruption.

### Fit within the Normal and Existing Operational Procedures of Shipboard Personnel

Commercial vessel crews are quite small and usually fully taxed with current operational procedures. Therefore, any new system must be easy to operate and maintain. Ideally, this means the system can be fully remotely controlled from the ballast control console and not require attendance in the engine room or pump room by an engineer. To relieve the crew of additional duties when in or near port, which is typically a busy time for shipboard personnel, its operation should be automated and not require constant monitoring or intervention. Likewise, durability and ease of maintenance is desired. Reliability must be especially considered with regard to ultimate efficacy standards – will the ship be prevented from discharging ballast if the treatment system becomes unavailable due to mechanical failure?

### Minimize Initial Capital and Life Cycle Costs

The full economic impact of the treatment system, including initial purchase, installation and long-term operational costs, must be considered. The long-term costs depend on system reliability, durability, cost of spares and ease of maintenance. Designing for proper access for routine maintenance, such as filter element or bulb replacement, is essential. For some larger systems 1.5 to 2.0 m of clear space around each treatment unit may be required for access.

### Meet the Existing Safety Standards of the Industry, Regulatory Bodies and the Target Vessel Operating Company

Most importantly, the treatment system or method should not pose any unreasonable health risk for the crew. It should also not create a higher risk for vessel safety nor require exceptions to the vessel owner's safety procedures.

The equipment installation and operation procedures must also meet Classification Society, Flag State, and Port State control authorities' requirements. This may include special pressure vessel or hazardous space design guidelines.

## 2.4 Biological Sampling and Equipment Monitoring Options

Any treatment system must have methods to monitor and evaluate its effectiveness. This is important for prototype testing of new technologies and determining if effectiveness standards are met. This is also important for making sure that, throughout the life of the system, it is performing as designed. Eventually, regulatory bodies will want to see data logs or records of system monitoring as they check for rule compliance.

The testing methods used for prototype evaluation are naturally more extensive and rigorous than those required for in service monitoring. When evaluating treatment systems, it is important to determine if they can be designed to provide the following sampling and monitoring capabilities.

### Automation and Alarms

Automatic data logging devices should be provided that are connected to mechanical/electronic sensors that measure key performance indicators. Ideally, these will not require regular operator intervention. The sensors may include pump usage and pressure recorders, flow rate meters, light intensity meters, particle counters, turbidity meters, etc.

If alarms go off that indicate the system is not performing up to specification, options should be available to the crew.

### Initial Extensive Sampling for Biological Evaluation

The biological sampling for prototype systems requires sampling ports before and after each component of the system. These should be 1" pipes introduced into the middle of the flow stream with a valve and hose for easy distribution of the sampled water to sampling/testing tubs.

It may also be necessary to have direct access to ballast tanks for sampling. Critical to this endeavor are the following factors:

- Location of manholes and whether these can be opened when the tank is full. To assess species density, it is best to take samples from all depths of the tank. This can be accomplished from a manhole at the top of the tank if there is a clear drop down through structure for the sampling net.
- Location of sounding tubes. If manholes are not accessible, samples can be taken through the sounding tubes. However, this limits samples to the very bottom of the tank and is really adequate only for assessing water quality (total salinity, etc.).

**Routine Sampling to Insure Proper Operation**

The biological sampling for occasional/periodic system efficacy checks requires sampling ports at least before and after the complete system.

**Reporting**

Automatic electronic data logging of key system performance monitoring sensors should be provided if possible.

## 2.5 Bypass Options

There should also be a complete/partial system bypass available.

# 3. TREATMENT SYSTEM OPTIONS

There are currently a wide variety of treatment options for ballast water being proposed by various industry and vendor groups. These include heat, cyclonic separation, filtration, chemical biocides, ultraviolet light irradiation, ultrasound and magnetic/electric fields [1]. Several of these systems exist in industrial applications today and some have been tested for their biological effectiveness in ballast water treatment.

While some have been shown to be quite effective against certain types of aquatic life, a single technique has not yet been found that can handle all of the target organisms with reasonable dosages or equipment parameters. The biodiversity is just too great (in terms of size and sensitivities). Differences in the size of ships and the quantities of ballast water handled, add to the complexity of the ideal solution. Finally, a ship's trade route may alter the primary target organisms when a risk-based approach to control of species is introduced or regional standards are encountered.

For these reasons, most investigators currently believe that a two- or three-stage treatment system offers the most flexibility and potential for addressing a wide range of organisms. The different components would be complementary and designed to address the organisms to which each is best suited.

For example, ultraviolet light irradiation or chemical biocides could conceivably be used as a single stage treatment. However, the dose would have to be very high to be effective in turbid water and for the very large organisms. Similarly, filtration could conceivably be used as a solo treatment if the mesh size were very small (less than 1 micron), however, filters of this size cannot process large quantities of water. Therefore, a combination of both filtration and UV may offer a more practical solution. A 100 micron filter is straightforward, provides some level of improvement in water transmittance, and takes care of the large organisms. With this prefiltration, the UV or chemical dosage can be reduced to a minimum level adequate just for the smaller organisms.

The recent studies did not endeavor to fully evaluate all candidate technologies, but rather selected treatment options that currently appear to be the most practical and acceptable alternatives [1]. They are commercially available at this time, are used in other industrial applications, have been tested for efficacy, or were desired for investigation by the ship owner. These are cyclonic separation, filtration, UV irradiation and chemicals. They are combined in two- or three-stage systems to best handle the operational realities of the target ships. The goal was to take the best existing technologies and see if they meet the shipboard practicality requirements.

The following sections describe the individual treatment systems and report on their biological effectiveness and other characteristics. The efficacy of combined systems is presented. Final selection of systems for each target vessel is discussed further in the ship-specific sections of the report.

## 3.1 Cyclonic Separation (CS)

**Description**

Cyclonic separation is normally accomplished with a hydrocyclone. The hydrocyclone, illustrated in Fig. 2, has no moving parts. Water enters at the bell-shaped end through a tangential inlet, and exits at a centered, flanged connection at the opposite end. Solids heavier than the primary fluid are removed at 5% to 10% of the total flow rate through a small discharge pipe located at the discharge end of the separator.

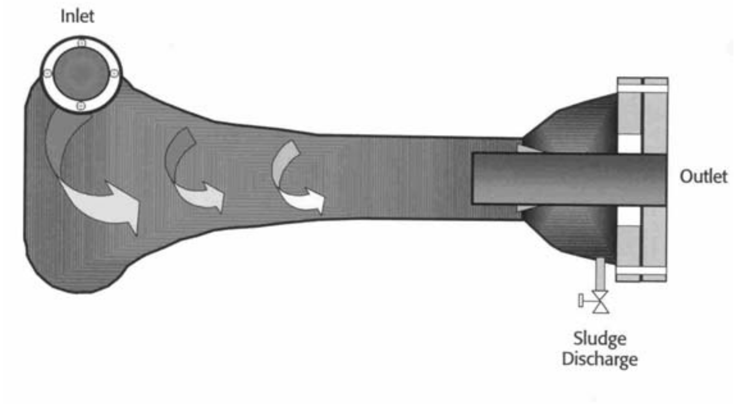

**Figure 2. Typical Cyclonic Separator – Hydrocyclone**

The pressure drop through a typical hydrocylone is about 0.8 bar (26 feet of seawater). To ensure that there is sufficient backpressure to force sludge out of the sludge discharge line against a head of seawater, a pressure regulating valve is also installed after the hydrocyclone. This backpressure valve (BPV) is set at 1.2 to 1.5 bar above the inlet pressure when the tanks are empty. As ballast water enters the tanks, the levels inside and outside the vessel change and the $\Delta P$ is reduced. As this happens, the BPV will gradually open. When the water levels are equal, the BPV is fully open and will remain so during the topping up of all tanks.

A few important notes regarding shipboard installation of hydrocyclones:

- They should be installed as vertical as possible with the inlet at the top. They can be inclined if overhead space limitations exist, but performance may suffer as they approach a horizontal orientation.
- A 3/16" to 3/8" screen mesh is recommended at the seawater intake to remove very large organisms.
- Gravity filling of tanks through a hydrocyclone will not work because the gravity head cannot push solids overboard.
- They are particularly applicable on the ballast intake cycle where the separated particles can be discharged with a small percentage of the pumped water back into the harbor of origin.
- They have the advantage of being scalable to even the largest ballast pumping rates found on ships. Either a single very large unit or a bank of smaller hydrocyclones in parallel can be used to achieve the desired throughput. It also may be possible to arrange units in series and optimize each for a different particle size or density. Note: total throughput to ballast tanks is still limited by pump capacity, increased system pressure and volume of diverted sludge.

## Efficacy

Cyclonic separation in shipboard applications can be expected to remove entrained particles that are heavier than seawater. This will effectively remove some suspended solids.

However, recent testing suggests that cyclonic separation is not effective in reducing total zooplankton density (it did not remove planktonic organisms), but it may reduce live densities (after some retention time) possibly due to damage during passage through the separator. One study suggests that the cyclonic separator reduced the density of live zooplankton slightly after retention in the catchment tank, but the results were not statistically significant [6].

As expected, cyclonic separation is also not very effective in reducing bacteria, viruses or phytoplankton (chlorophyll *a* concentrations or algal growth). These organisms are small and neutrally buoyant [6]. For a similar reason, this equipment is not particularly effective in reducing turbidity and increasing light transmissivity of the ballast water.

## Conclusions and Assumptions

Cyclonic separation can provide a practical first-stage treatment solution. It is attractive because it is proven and available technology, has simple retrofit capability, has small impact on existing ship pumping capabilities and provides automatic operation. By removing potentially damaging particles, it can be an important pre-treatment for a second stage that can address the smaller remaining life forms. However, it does not remove turbidity, especially dissolved materials, and this must be considered when predicting the effectiveness of the second stage treatment system.

## 3.2 Ultraviolet (UV) Light Treatment

### Description

Ultraviolet (UV) light in wavelengths from 200 to 280 nm can effectively inactivate bacteria, viruses, and other living organisms. The inactivation is caused by DNA mutations induced through absorption of UV light by DNA molecules. For disinfection of water (removal of human pathogens and viruses), the U.S. FDA requires that all parts (each volume element) of the product receive a UV radiant exposure of at least 400 J/m$^2$ (40 mWsec/cm$^2$) at a wavelength of 254 nm. [7]. UV irradiation has been the subject of laboratory testing on a range of marine organisms as well, and was found to be most effective in the wavelengths from 250 to 260 nm.

This technology is well understood and is in widespread use in related fields such as fish farming, sewage treatment and offshore oil production. A typical UV unit designed for shipboard use is shown in Fig. 3. In this unit, water flows across a bank of UV bulbs that are contained in individual closed quartz tubes to protect them from the flow. The UV light intensity is automatically controlled by the power supply and monitored by a sensor inside the unit. It is designed to deliver a dose of at least 100 mWsec/cm$^2$ in water with a 90+%/cm UV transmittance at 254 NM/cm.

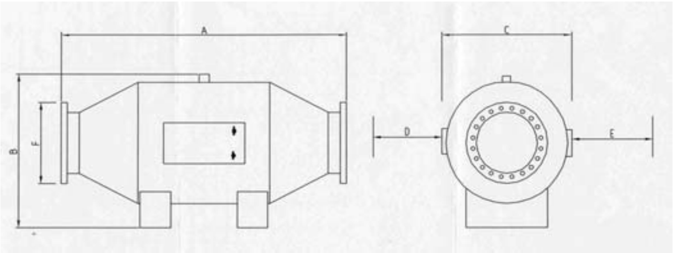

**Figure 3. Typical UV Unit**

The determination and definition of this rated dosage is critical to the ultimate biological effectiveness of the UV unit. Designing a system than can provide the required inactivation dosage (40 mWsec/cm$^2$) reliably and evenly, to all cells of the target organisms in the ballast water flow, is the key to successful treatment. The output of the UV light source is not a good indication of this. The rated dosage is usually set to account for the geometric configuration of the tubes and flow path, flow rate (and time of exposure), size of target organisms, and transmissivity of the expected ballast water. All of these factors are critical to ensuring that the required inactivation dosage reaches into all the organisms.

### Turbidity, Transmittance and Transmissivity and UV Performance Issues

Turbidity in the water can be caused by suspended particles or dissolved materials, and is characterized by water cloudiness. The particles in turbid water can be quite small (5 micron range) and hence difficult to remove. Turbid water absorbs light, resulting in low dose rates or less exposure of the organisms to the UV light and less microbial inactivation. Larger particles in the water will interfere with the light, rather than absorb it, essentially blocking the light from penetrating through the entire water volume undergoing irradiation. These particles can be easier to remove than dissolved materials, as they are usually larger and in some cases may be heavier than water and can be separated.

The terms “transmittance” and “transmissivity” are used interchangeably, and refer to the overall absorbency and/or interference characteristics of the water.

UV treatment unit ratings should include minimum acceptable transmissivity levels to ensure target performance, and then pretreatment should be provided to insure this transmissivity is achieved. Note that dissolved materials can be quite small (5 micron range) and difficult to remove.

To verify that UV radiant exposure exceeds the required inactivation levels during operation, a sensor designed to measure the amount of ultraviolet light being received on its surface must be provided. Care should be taken so that changes in the output of the light source (due to age or fouling) and fouling of the detector surface can be separated from changes in the transmissivity characteristics of the media to be disinfected. Because one sensor can monitor only 1 or 2 lamps, in systems with several lamps, all UV lamps need to be monitored through electrical parameters and a lamp failure alarm provided. Additionally, all UV lamps in a system unit should be of the same age and quality, and the quartz of the glass panel must be guaranteed by the manufacturer and documented through identification marks.

## Efficacy

Recent full scale tests [6] have shown that it is difficult for current UV equipment to produce inactivation rates approaching 100%. There are a few practical system variables and constraints that conspire to reduce the effect of the UV treatment. These include limitations of pretreatment and higher than ideal turbidity of ballast water. UV equipment technology needs to continue to evolve to address these problems and achieve its full potential. Additional testing is also required to assess latent effects and regrowth rates of partially inactivated species.

It should be noted however, that UV treatment can be accomplished both during ballasting and deballasting. This greatly improves the biological effectiveness of the entire treatment system because it can remove any organism regrowth that may occur in the ballast tank.

Specific test results of a two-stage treatment system (cyclonic separation + UV) on a test barge and on board the cruise ship *Regal Princess* revealed the following [8]:

- UV was proven effective against zooplankton, phytoplankton, bacteria and viruses.
- There is a direct relationship between UV transmittance and percent inactivation of bacteria and viruses, and chlorophyll a. As an indicator, one set of tests showed the following correlation:

| UV transmittance | 30-45% | 90-95% |
|---|---|---|
| Mean inactivation for bacteria | 25% | 90% |
| Mean inactivation for coliphage MS-2 virus | 50% | 95% |
| Reduction of chlorophyll *a* concentrations | 32% | 57% |

Note, UV unit designed for 100 mWs/cm$^2$ dosage.

Based on these test results, a UV system designed for a 90% transmittance should deliver the following performance:

- Reduce bacteria by 90%.
- Reduce the MS-2 coliphage virus by over 90%.
- Reduce phytoplankton growth potential (chlorophyll a concentrations) by over 50%. BUT without 100% mortality, some phytoplankton survives with the capability to regenerate, albeit at slower rates. Holding the phytoplankton in dark tanks seems to increase the mortality rates.
- Reduce the concentration of live zooplankton relative to controls, especially if treated on intake and discharge. Zooplankton is weakened by first treatment, continues to die off in the ballast tank, and suffers the greatest kill/removal rate on discharge. More die off after discharge because of latent damage.
- With combined cyclonic + UV and treatment on intake and discharge, one should expect 90% reduction in live zooplankton density. This expectation is based on the *Regal Princess* results.

## Conclusions and Assumptions

UV light irradiation appears to hold considerable promise for practical, successful secondary treatment because:

- UV has the potential to be very effective against all of the target organisms. It may even be possible to increase irradiation intensities to address turbid water conditions with low transmittance. To account for varying turbidity and transmissivity levels, optional automatic control of bulb intensity or ballast water flow rate could be provided.
- UV has a long history in the marine industry and demonstrated low maintenance requirements.
- New developments in UV unit design utilizing multiple lamps in a cross-flow configuration, show potential advantages.
- The basic technology is readily available on the market for both low and high flow rates. Even for high flow rates (3000 m$^3$/hr), the physical size is not unreasonable (about 4 m long, 2 m in diameter).
- UV permits treatment in both ballast and deballasting operations.
- UV creates only a small pressure drop and requires simple piping connections.

- UV is capable of automatic operation with electronic monitoring and alarms.
- UV light does not change the physical characteristics of the treated water and is environmentally friendly with no known toxic by-products, residuals or lasting effects.

## 3.3 Filtration with Backflush

**Description**

Filtration is a simple concept, but available filter technology covers a wide spectrum including screen, cloth, pre-coat disk type and membrane filters. The selection of filter type is driven in part by the size of the material to be removed. Viruses and bacteria require membrane filters effective to 0.01 micron. This is extremely small and the membrane technology is quite expensive, requires prefiltration of 50 to 200 microns, and may not be able to provide the flow rates required in a shipboard application. For bacteria removal, membrane filters have been found to be considerably more expensive than UV irradiation [9].

The primary focus for filtration of ballast water treatment has been on screen filters for pre-filtration in preparation for a secondary treatment for the smaller organisms. More recent tests on disk filters show positive results. The target particle size for the filter stage, as mentioned earlier, is in the 50 to 100 micron size range. Prototype testing aboard a barge indicated that 50 microns is probably the practical lower limit for shipboard use [3].

Testing has also demonstrated the following:

- A 5-10 mm (3/16" to 3/8") prescreen upstream of the filter is required to protect the finer screens.
- Automatic backflush capability is required to allow for unattended operation however, the backflush process can reduce the net flow rate and increase the system pressure drops. Real in-service experience has shown that the reduction in flow rate can be quite different from test-bed values.
- A pressure sustaining valve is required downstream of the filters to maintain the pressure differential between the discharge chamber and backflush chamber. This valve can have a possible impact on pump performance.
- Backflush timing in service can vary greatly from system test-bed values.
- For larger units, handling of filter screens by crew must be addressed.

When selecting filter units for treatment applications, these issues should be carefully considered. Filtration systems that can maintain a high flow rate with little pressure drop should be sought out. Systems that do not offer this capability may not be suitable for retrofit applications because of the associated cost of upgrading ballast pumping capacity to compensate for the lost flow rate and pressure head.

One vendor of filters with 130 micron screen size and a 350m$^3$/hr flow rate, predicts a 0.14 bar pressure drop through the filter media when it is clean. Backflushing is set to commence when the pressure differential reaches 0.2 to 0.28 bar. How frequently this occurs depends on the quantity of suspended solids and organic life in the ballast water. In order to push the accumulated sludge clogging the filter against the head of a deep waterline for external discharge, an additional, external backflushing pump is required with a head of 4-5 bar.

For high flow rates and ballast volumes such as those required by tankers and bulkers, filtration systems with automatic backflush capability are probably not practical.

### Efficacy

Filtration in shipboard applications can be expected to remove most of the larger life forms. A 50 micron screen will also remove most or all of the zooplankton [9] and some of the phytoplankton and dinoflagellates. Filters of a practical size are not effective against bacteria and viruses.

A secondary benefit, moreover, is that the filters are useful in reducing certain types of turbidity in the ballast water since they also remove suspended solids.

### Conclusions and Assumptions

Filtration can provide a practical 1st stage treatment solution. It is attractive because of its ability to remove most suspended particles of a pre-determined size, including turbidity-creating solids. Filters are also a readily available technology and have the potential for automatic operation.

## 3.4 Chemical Biocide Injection

### Description

Chemical biocides, such as chlorine and glutaraldehyde, are currently used in industrial water treatment facilities. Biocidal treatments proposed for shipboard use also include SeaKleen (a brand name), juglone and acrolein. The chemical treatment could be administered by metered injection into ballast fill lines to insure adequate mixing and the proper application rate. The chemical injection equipment required, is relatively inexpensive to install and requires little ship resources in terms of space and power. Alternatively, chemical dosing packets could be added directly to tanks.

Research in the use of chlorine, glutaraldehyde and SeaKleen are currently being conducted. Research to date appears to lead to the following conclusions regarding biocidal treatments:

- Biocides are effective in eliminating aquatic organisms as either a primary or a secondary treatment.
- The use of pre-filtration (to about 150 µm) can significantly reduce the chemical concentrations required for effective treatment.
- Shipboard application of biocides can be readily implemented, but risks of chemical exposure to the ship’s crew must be addressed with proper safety procedures.

- Biocidal agents generally decompose at some rate over time and, depending on the concentration applied, in many circumstances could be released untreated at the end of a ship's voyage. At high application concentrations (and for some chemicals at any concentration), treatment of the biocide residue would be required. Agents will also decompose at different rates depending on sediment loading in the ballast tanks and on the concentration of the agent applied.
- Biocidal treatments are believed to be a technically and financially feasible method for treating residual ballast sediment in tanks.

As noted, chemical treatment does carry with it special concerns regarding the safe storing, handling and dosing of the material on board ship. However, the most potentially onerous hurdles involve the chemical residuals and their toxicity implications. Obtaining approval for the discharge of chemically treated water may be quite difficult. Current efforts to initiate full-scale trials for SeaKleen will demonstrate how difficult this might be.

As an example of the quantities of material required, consider the use of SeaKleen. The chemicals are handled and mixed in 55 gallon drums to 5% solution strength. A 1 ppm solution is required for the desired kill/removal rate (requiring about 1 gm/mt of ballast). Therefore, for a 360 $m^3$/hr ballast flow rate a solution injection rate of 120 ml/min or 7.2 l/hr is required. A 55 gal drum of 5% solution would last 30 hours. The half-life of the chemical's biocidal properties is less than 24 hours and it degrades to non-toxic products. This, theoretically, allows for safe discharge of treated water but it also requires that the 5% solution be mixed just prior to use.

## Efficacy

Chemical treatment is not currently believed to be a stand-alone treatment because of the high dosages required to kill larger organisms. However, with pre-filtering and adequate mixing of the biocides with the ballast water, the kill/removal rate can be very high. As with other systems, the final biological effectiveness depends on how closely the theoretical dosage and organism matches that achieved in practice.

## Conclusions and Assumptions

There are two situations when chemical treatment might be particularly useful. It could be a failsafe system used in conditions where the primary and/or secondary systems are rendered ineffective (such as when turbidity limits exceed design specifications for UV units). It can also be useful for treating NOBOB tank mud/slops.

However, it may be very difficult to obtain approval for the use of chemicals by ships where the dosage cannot always be carefully monitored and the holding time guaranteed. This is where the Globallast criteria of "environmentally acceptable" will be carefully applied.

## 3.5 Other Developing Technologies

Numerous other treatment methods have been proposed. These include Ozonation, Electric Pulse and Pulse Plasma, ultrasound, magnetic/electric fields, heat and deoxygenation. While studies of technical and economic feasibility are in process or have recently been completed for some of these, none was ready for full commercial application during this study.

Because of this, none of these other treatment methods were considered for the current design studies, in keeping with the stated goal of using good candidate technologies that are currently commercially available.

However, two additional methods are worth noting: simple pumping, and altering ballast management practices.

Preliminary tests suggest that the mechanical damage caused by pump impellers is somewhat effective at killing zooplankton. Pumps do not appear to have a detrimental effect on bacteria or phytoplankton.

For new ships of certain types (e.g. containerships) designs permitting better ballast movement on board may eliminate the need for treatment. Also, changing ballast procedures to include ballasting in deeper water, ballasting during the day instead of at night when some organisms rise closer to the surface, and ballasting from high sea suctions instead of those near the seabed, may help reduce or eliminate the need for treatment.

In the case of new ship design and construction, it is certainly possible to simply design the ship for no external ballasting. The new TOTE Trailerships currently under construction at National Steel and Shipbuilding Company (NASSCO) show one example of this approach.

# 4. TARGET VESSELS

Two ship types were selected to represent major vessel types and operations on the West Coast: the TAPS trade tanker and the containership. The new Polar Tankers' *Polar Endeavour* (Fig. 4), the first delivery of the Millennium Class, was selected as the tanker for the study, and the existing Matson containership *R.J. Pfeiffer* (Fig. 5) was selected as the containership.

Ship owners Polar Tankers, Inc., and Matson Navigation supported this project. Their ships call at U.S. ports including some of the most sensitive areas such as San Francisco, Puget Sound and Valdez, Alaska. Polar Tankers, Inc., is currently operating a fleet of tankers in the U.S. domestic trade between Alaska and the U.S. West Coast. Matson Navigation is a U.S. domestic carrier operating a fleet of containerships between the West Coast and Hawaii.

## Design Study #1
## "Other Vessel of 10,000 MT Displacement or Greater"

| | |
|---|---|
| Vessel Name | *M/V Polar Endeavour* |
| Vessel Type | 125,000 dwt Crude Oil Carrier |
| Year Delivered | 2001 (new building) |
| Owner/Operator | Polar Tankers, Inc. |
| Length Overall | 272.69 m |
| Beam | 46.20 m |
| Depth | 25.30 m |
| Draft | 16.31m |
| Deadweight | 127,005 MT |
| Ballast Capacity | 60,700 $m^3$ (55,000 $m^3$ used for heavy ballast condition) |
| Number of Ballast Tanks | 6 pairs main tanks + 1 forepeak tank + 4 aft tanks |
| Ballast Pumping Capacity | 2 at 2,860 $m^3$/hr, main pumps<br>2 at 1,000 $m^3$/hr, aft pumps |

### <u>Characteristics of Polar Endeavour</u>

1. Large volume of ballast and large pumping capacity with both pumps typically in use for ballast operations. Excellent comparison with other target ship types with lower ballast pumping requirements.

2. Dependence on gravity feed for loading and discharging ballast for operational efficiency.

3. Because of its trade routes between Puget Sound and other West Coast ports and Prince William Sound (PWS), it ballasts and deballasts in environmentally sensitive ports.

4. Could be a candidate for incentives (from the California State Lands Commission and the State of Washington Aquatic Nuisance Species Coordinator) to install the proposed system.

**Figure 4.** ***M/V Polar Endeavour***

**Figure 5.** ***M/V R.J. Pfeiffer***

### Design Study #2 – "2000 TEU or Greater Containership Regularly Calling at U.S. Port"

| | |
|---|---|
| Vessel Name | *M/V R.J. Pfeiffer* |
| Vessel Type | 2,000 TEU Containership |
| Year Delivered | 1992 |
| Owner/ Operator | Matson Navigation Company |
| Length Overall | 217.47 m |
| Beam | 32.21 m |
| Depth | 20.27 m |
| Draft | 11.58 m |
| Deadweight | 28,758 MT |
| Container Capacity | 2420 TEU |
| Ballast Capacity | 14,600 $m^3$ |
| Ballast Tanks | 26 |
| Ballast Pumping Capacity | 2 at 350 $m^3$/hr |

**Characteristics of *R.J. Pfeiffer***

1. This vessel is a typical Panamax containership with ballast in the double bottom and wings used to maintain stability as well as control trim and list. It was selected over post-Panamax sized vessels because the larger vessels have much more flexible ballasting options and can often avoid port discharge through careful planning.

2. Only one ballast pump is used at a time providing a flow rate of 350 $m^3$ per hour.

3. The required system capacity is essentially identical to the system installed on the GLBTDP barge [2, 3].

4. Because of its trade routes on the U.S. West Coast and in Hawaii, it ballasts and deballasts in environmentally sensitive ports. Biological data for these ports are readily available.

5. This ship is a candidate for incentives (from the California State Lands Commission and the State of Washington Aquatic Nuisance Species Coordinator) to install the proposed system.

# 5. DESIGN SUMMARY – *POLAR ENDEAVOR*

## 5.1 Vessel Ballast System Characteristics, Ballasting Practices and Common Port Calls

*Polar Endeavour* is entering service this year in the Trans-Alaska Pipeline System (TAPS) trade on the West Coast. The ship is designed to deliver North Slope crude oil from Valdez, AK, to the U.S. West Coast ports in Puget Sound, San Francisco, Long Beach (CA) and Hawaii.

There are two ballast systems on the vessel: the primary system consisting of two 2,860 $m^3$/hr (12,600 gpm) pumps serving the six pairs of forebody tanks and a single forepeak tank (both main pumps are typically used simultaneously); and the aft ballast system consisting of two smaller pumps serving four small tanks in the aft end of the vessel. The primary system also has an eductor system for stripping the forebody ballast system, and the aft ballast system is used to control trim and list.

Tanker ballasting operations are characterized by moving large volumes of ballast each trip. The ship must have a minimum draft when not carrying cargo to control hull stresses, provide good seakeeping and maneuvering, and provide propeller submergence.

Deck officers, or mates, perform the ballasting operations from the cargo control room. Pumps and valves are controlled by the ballast control system, which is part of cargo control.

"Gravitating" ballast is an important component of the *Polar Endeavour*'s ballasting operations. Gravitating is allowing water to flow into or out of the tanks using the head differential, or pressure difference, between the tank level and the outside water level, and not using pumps. The ability to gravitate reduces the owner's cost because of reduced pump operating time, and it provides simpler and more efficient operations for the crew.

The timeline (Table 2) roughly describes the anticipated operations of the vessel, without consideration of ballast water treatment. These are anticipated operations and may not represent the actual operations that will be developed after introduction of this new vessel.

Gravitating ballast is not possible in a treatment system that uses a cyclonic separator. The available head differential, or $\Delta P$, may not be adequate to overcome the minimum required pressure drop in the cyclone to maintain the vortex. Without gravitating, additional pump time is necessary. Additionally, pumping time is extended further due to the added resistance in the system and reduced flow rate, as well as the lost 5 to 10% capacity due to the sludge return from the cyclonic separator.

Table 3 summarizes the impact on ballast pump times. These data were developed using a piping system flow model of the *Polar Endeavour*'s ballast system that accounts for the changing tank levels during the pumping operation, the resistance of each component and the actual pump performance curve.

Increased pump usage is accounted for in the life cycle cost study in terms of pump maintenance increase and fuel cost associated with the additional electrical power generation.

One could presume that overall ship operation timelines would not be affected because pumping ballast will always be faster than gravitating ballast; however, because of the ship's generator power limitations, ballast pumps cannot operate simultaneously with full output of cargo pumps. If the CS and UV were installed, the 5 hour increase in ballast pumping time would have to occur during the 8 hours of transit time outbound from the refinery to the sea buoy. There is potential for the vessel schedule to be affected. Arriving in Prince William Sound, the vessel could still gravitate on the ballast discharge, as the water was treated on the intake. However, as the system is currently designed, this operation would bypass the second UV treatment on the discharge.

**Table 2. Vessel Operations Timeline – Anticipated**

| Time | Event |
|---|---|
| Day 1<br>Hour 0 | Enter Puget Sound at Cape Flattery with 125,000 dwt tons of oil at a 44 foot draft, no ballast on board. |
| Day 1<br>Hour 8 | Dockside, at the Puget Sound refinery, ballast is allowed to free-flood into the forebody tanks as cargo discharge begins. |
| Day 1<br>Hour 18 | The free-flood rate diminishes as the ship draft decreases, and ballasting operations are suspended. 29,000 tons of ballast is taken on by gravitating in this 10 hour period. |
| Day 2<br>Hour 2 | Cargo discharge is completed in a total of 18 hours of pumping. With power available for ballast pumps, they are started in order to finish ballasting. |
| Day 2<br>Hour 10 | After 8 hours of pumping, main ballast tanks are loaded to the *normal ballast condition*. Ship departs with 50,300 tons of main ballast on board. Aft ballast tanks are empty. |
| Day 2<br>Hour 18 | Ship clears Cape Flattery buoy heading northbound. |
| Day 3<br>Hour 12 | Ship encounters heavy weather and mates take on 3,300 tons of ballast in the aft tanks, 2,200 in the focsle tank and 4,300 in the #6's to get to the *heavy ballast condition*, with a total of 60,100 tons of ballast. |
| Day 6<br>Hour 6 | Ship arrives at Cape Hinchinbrook, entrance to Prince William Sound, and with a low sea state is able to gravity-drain ballast. |
| Day 6<br>Hour 12 | Vessel arrives at Valdez, and begins taking on crude oil. Both main ballast pumps are started to discharge ballast.<br>21,750 tons are discharged by gravitating. |
| Day 6<br>Hour 20 | Ballast tanks are empty, cargo loading continues. 38,350 tons are discharged by the main ballast pumps. |
| Day 6<br>Hour 22 | Cargo tanks full, ship departs southbound to Puget Sound. |
| Day 10<br>Hour 10 | Enter Puget Sound at Cape Flattery. |

**Table 3. Ballast Pumping Time Comparison**
**Filling Tanks with Cargo Discharge at Puget Sound Refinery – *Polar Endeavour***

| Procedure | Gravitating Time (Free Flooding) | Pumping Time | Total Ballasting Time |
|---|---|---|---|
| Gravitating and Pumping,<br>no Separator / UV treatment | 10.2 hours | 7.5 hours | 17.7 hours |
| Pumping Only,<br>no Separator / UV Treatment | – | 10 hours | 10 hours |
| Pumping Only,<br>with Separator / UV Treatment | – | 12.3 hours | 12.3 hours |

## 5.2 *Polar Endeavour* Treatment Philosophy and Functionality

We have selected treatment systems that either have demonstrated effectiveness (or look to be the most promising of the existing treatments tested) and that have the capacity to support the vessel's large ballast system with minimal impact on operations. For example, we are using cyclonic separators instead of filters because the ballast system rate is high for fine filtration applications.

To provide design and operational flexibility and so that various water contamination problems can be treated, we have also specified redundant systems and different types of systems. These different treatment systems have been estimated and engineered separately, but can be combined in a number of ways depending on:

- Final rulings from the regulatory bodies on acceptability of equipment.
- New efficacy information that comes available.
- New regulations that come into force.
- Owner preferences.

The main and aft ballast system primary treatment is in three stages. The first stage is to treat the ballast as it is taken aboard by separating heavier particles with a cyclonic separator unit. The sludge is immediately discharged back into the harbor of origin. The secondary treatment irradiates the cleaned water with ultraviolet light to kill or inactivate the organisms in the water. Interference with UV irradiation is reduced by separating solid particles before entering the UV unit. Since surviving organisms may multiply while in the ballast tank during the voyage, the third stage irradiates the water again when discharged in the receiving harbor.

An optional chemical treatment system is provided as either a fourth stage, an alternate secondary treatment, or a stand-alone alternate treatment. Incoming ballast water can run through the cyclonic separator and the UV, and then also be treated chemically, or the cyclonic separator and UV can be bypassed and the water only treated chemically.

If incoming ballast water is clean and without solids, the cyclonic separator can be bypassed and water run only through the UV. It is not possible in this system design, however, to run water through the separator and bypass the UV unit, although the UV can be de-energized and water flow through without irradiation.

Both the main and aft ballast systems will have this functionality. Each of the four pumps has an associated separator and UV unit; however, one chemical tank serves the four possible ballast supply lines with four separate dosing pumps. The aft system is smaller in scale and capacity than the main system, matching the aft ballast pump capacity.

An eductor system has the capability to strip the ballast tanks and pump directly overboard. Hence a fifth UV unit is provided in that discharge line to provide the third stage treatment – irradiating water flowing through that system as it may be discharged in the receiving harbor.

## 5.3 Description of *Polar Endeavour* System Equipment

The following treatment equipment was selected for installation in the *Polar Endeavour*:

**Main Ballast System, Capacity 2860 $m^3$/hr x 2 pumps**

- Cyclonic Separators (2): MicroKill Model 3000 (Capacity 2,700 to 3,200 $m^3$/hr)
- UV Light Treatment (2): MicroKill UV Model MP600-08-7300 (Capacity 3,000 $m^3$/hr @ 120mWs/$cm^2$)

**Eductor System, Capacity 500 $m^3$/hr**

- UV Light Treatment (1): MicroKill UV Model MP300-02-2500 (Capacity 500 $m^3$/hr @ 50mWs/$cm^2$)

**Aft Ballast System, Capacity 1000 $m^3$/hr x 2 pumps**

- Cyclonic Separators (2): MicroKill Sep Model 1000 (Capacity 800 to 1200 $m^3$/hr)
- UV Light Treatment (2): MicroKill UV Model MP300-04-2500 (Capacity 1000 $m^3$/hr @ 50mWs/$cm^2$)

**Chemical Treatment, Capacity to treat 60,000 tons ballast at 5,720 $m^3$/hr ballast rate.**

- SeaKleen Chemical Treatment System: One 200 gallon tank with four feed pumps, each sized for 30 liters per hour. Tank's 200 gallon capacity is sized for chemical volume required to treat full 60,000 $m^3$ ballast volume of ship.

## 5.4 *Polar Endeavour* Equipment Installation Issues

Equipment installation in *Polar Endeavour*, and potentially in all tankers, is complicated because the ballast piping, pumps and valving are all located in the pump room, which is a hazardous area. The pump room also happens to be the most crowded, densely packed space on the vessel.

In addition, it is probably not possible to install a UV unit in that space because it would introduce electrical equipment and its wiring in a hazardous area. Electrical equipment in hazardous areas is not allowed unless "essential for operation purposes." The electrical equipment that can be allowed in the pump room must be intrinsically safe, and so far an intrinsically safe UV unit is not available.

There are three potential solutions to the problem:

1. Route the ballast piping out of the pump room up into a small UV unit compartment accessible from the engine room and install the UV unit in that space.

2. Continue in the development of an intrinsically safe unit and also gain acceptance from the regulatory bodies that the unit is essential for operation purposes. OptiMarin has European agency explosion proof certification for a unit)

3. Drop the UV unit and proceed with other alternatives.

Option 1 would be the best choice, but it is not easy to accomplish given the pump room space arrangements and physical size of the piping. Also, ABS rejected the option because the ballast piping would pass through the engine room space where sources of ignition are present. This alternative is shown in Figure 6.

Additionally, although the lamps are isolated from the internal volume of the ballast piping with quartz sleeves, the internal piping may also have oil vapors when dry. This problem can be addressed by installing a flow sensor on the piping that does not allow the UV unit to be energized unless the pipe is full of flowing ballast water.

We proceeded with developing the contract plans for the installation, and the UV unit is included in the drawings. The concept has been generally accepted by the American Bureau of Shipping (ABS) and the U.S. Coast Guard, pending development of an explosion proof unit that can be approved for use in pump rooms. ABS comments on this installation are provided in a later section of this report.

There is a space issue that also relates to the installation of the cyclonic separator. There is not enough vertical clearance to install the CS in its normal vertical orientation; hence it is installed horizontally. The vendor indicates minimal detriment to performance, but it should be noted that there has been no testing of the CS in this configuration, and performance is not verified.

The aft ballast systems are much easier to install because the components can all be in the spacious engine rooms, and not be subject to the space and hazardous location constraints of the pump room. System diagrams are provided and the arrangement of the aft ballast system in the engine rooms can be developed and detailed by the shipyard.

The chemical treatment system is the simplest and least-cost installation and requires very minor storage facilities and tank volume. However, before discharge of the chemical is accepted, approval of all regulatory bodies (federal, state and local) is required. The regulatory approval process may be long, and may not be resolved by completion of this study – hence the optional nature of this chemical treatment system.

SeaKleen is the chemical identified for this study; the following engineering, design and cost information is used in this report, as stated by the manufacturer.

- The chemical is a water-soluble powder. One kg of powder is mixed with 10 kg of water, which treats 1,000 metric tons of seawater.
- To treat 60,000 metric tons of ballast we would need 60 kg (132 lb) of powder mixed in 600 kg (1,322 lb or 160 gal) of fresh water.
- SeaKleen is a natural biocide, relatively safe compared with other chemicals. It has no particular storage or handling problems or unusual safety concerns.
- Toxicity diminishes over time so that it is relatively benign by the time the vessel reaches the ballast water receiving port and is ready to discharge ballast.
- Current cost estimates from SeaKleen indicate about $0.20 per ton of seawater treated, based on laboratory production of the chemical. This equates to about $200/kg of dry chemical. The final cost may be as low as one-half this cost, which is addressed later in life cycle cost estimates.

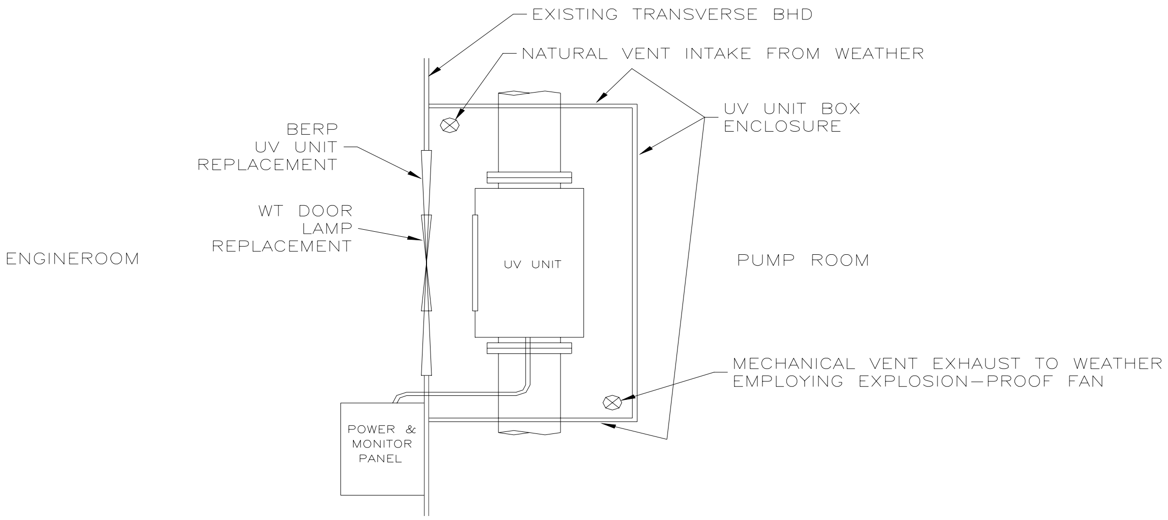

**Figure 6. Alternate UV Unit Location**

The chemical must be mixed just before ballasting, as degradation of the biocide begins as soon as it is mixed with water. A 200 gallon tank is specified because the chemical is mixed for each trip. A storage area is required, suitable for 900 kg (2,000 lb) of dry, powdered SeaKleen, which is adequate for about 15 trips. The entire system will be installed on one or two of the flats in the vertical access above the pump room.

SeaKleen may be manufactured in pellets, which would make it easier to store and use.

## 5.5 System Setup, Operation and Equipment Monitoring

Ballasting operations will become significantly more complex for the ship's crew, although nothing that cannot be accommodated. Ballasting operations and monitoring would include:

**Operation of the Cyclonic Separator**

Exit pressure is automatically monitored and the backflow pressure valve automatically adjusted with the changing draft of the ship. The sludge line will have a flow meter, and much of the other monitoring can be done with the automatic control and monitoring system.

**Operation of the UV Unit**

Operation of the UV unit is set up to be automatic. Initial energizing of the unit at the controller will be linked to the ballast pump startup, and final energizing will be linked to the flow meter in the piping. The light transmittance is monitored and recorded, along with temperature. The unit control panel logs the data, and a summary alarm is added to the ship's machinery monitoring system to indicate if ballast is flowing but transmittance level is below threshold.

**Operation of the Chemical Treatment System**

Operation of the system is relatively automatic, with most of the impact on the crew occurring in the setup of the system and mixing of the chemical. The proportioning pumps will be energized in conjunction with the corresponding ballast pump. Chemical flow will be monitored and again alarmed if the flow rate is below specification.

Mixing of the chemical in the nurse tank, although relatively simple, will be a new operation for most crews. First, approximately 0.6 $m^3$ (160 gal.) of fresh water is metered into the tank. The chemical tank will have a sight glass for level indication. Then 60 kg (132 lb) of powder (or pellets) is added through a hatch in the top of the tank. The dry chemical will be stored in an expanded metal cage adjacent to the tank. Access platforms and fixtures to aid in the pouring of the chemical will be provided.

Given the sensitivity of the chemical dosage and short duration of its effectiveness, a dry chemical dispensing system should be developed, to dispense 10 kg at a time with a coordinated metering of 100 kg (27 gal) of water.

For automatic dispensing of the chemical into the ballast tanks when gravitating, a second dispensing rate will need to be determined so that, at the end of the gravity fill, the proper amount of chemical will have been added.

## 5.6 Sampling and Treatment Performance Monitoring

Means must be provided to sample the ballast water on board to determine treatment effectiveness. It is intended that the ship's crew will perform this function, but on occasion a trained science technician will come aboard to test the efficacy of the system. Sampling ports are provided in three places: incoming ballast before the cyclonic separator, outgoing ballast after the UV treatment, and at the sludge discharge.

A simple test kit will have to be developed and supplied to ships' crews, and they must be trained in its use.

## 5.7 System Maintenance

Maintenance of the ballast water treatment systems specified is relatively low. There is no maintenance on the cyclonic separator, and the UV unit only needs lamp replacement and occasional calibration of the light intensity monitoring equipment. The chemical treatment system also should require little maintenance.

A section that follows on life-cycle costs includes the effect of the system on ballast pump maintenance (from increased usage).

## 5.8 Personnel Training and Safety

The proposed systems do not present any particularly problematic training or safety issues. The systems are much less complex than many of the other systems on the vessel. Safety issues relating to the handling and storage of the chemical are minor. Coveralls, gloves and face masks will be all that is necessary.

## 5.9 *Polar Endeavour* Shipyard Scope of Work

The treatment systems on the *Polar Endeavour* are divided into four areas of work. The owner can select these components for implementation either individually or collectively. They are:

1. *Main ballast system cyclonic separators*. The ballast system piping will be modified to install the cyclonic separators (two, one for each ballast pump) as shown on the drawing, including its foundation, sludge lines and new dedicated overboard discharge. New hydraulic actuated valves will be installed with control integrated into the ship's ballast valve control system.

2. *Main ballast system UV light treatment units*. The ballast system piping will be modified to install the UV units (three total), as shown on the drawing, including foundation, control panel and power panel. Electrical power (480 VAC 60 kW each for the two main units and 5 kW for the eductor unit) will be fed from an auxiliary machinery power panel, and control and monitoring wiring will interconnect the equipment with the ship's alarm system. New hydraulic actuated valves will be installed with control integrated into the ship's ballast valve control system.

3. *Aft ballast system cyclonic separators and UV units*. The aft ballast system piping will be modified to install cyclonic separators (two) and UV units (two), as shown on the drawing, including foundations, sludge lines and new dedicated overboard discharge line. All equipment will be installed in the two main engine rooms, port and starboard. The new hydraulic valves will be remotely controlled by the cargo control system. Alarm and monitoring systems will be modified to allow the new inputs.

4. *Chemical treatment system*. The fresh water system will be extended to a flat in the vertical access above the pump room, where a 200 gallon fabricated tank will be installed. The fresh water piping will be arranged to meter into the tank (an air gap must be provided). On the

level above the tank the dry chemical storage area will be fabricated of expanded metal cage. The tank will have a hinged hatch in the top for adding the chemical. Independent supply piping will run to each of four air-powered diaphragm pumps for injecting the chemical, and chemical feed piping will run to the designated ballast mains.

## 5.10 Installation Cost Estimating Assumptions and Data

A budgetary cost estimate was developed for this study. An in-house historical cost database was used to generate the estimate. Typical estimating assumptions were made as follows:

- Shipyard labor rate of $50/hr. (Typical of US Shipyards)
- Shipyard engineering cost about 15% of the installation cost.
- Material markup of 15%. This is a fairly standard value among most yards.
- Estimating contingency of 12% on both materials and labor. This value is appropriate for this contract design level, particularly since we have firm quotations for the treatment equipment.

A summary of the estimate is provided in Table 4, with details provided in Appendix A.

## 5.11 Life Cycle Cost Analysis Assumptions and Data

The method for calculating life cycle costs is presented as follows:

*Life Cycle Cost* is the overall estimated cost for the particular modification over the assumed remaining life of the ship, including direct and indirect initial non-recurring costs plus any periodic or recurring costs of operation and maintenance. Life cycle cost is simply the sum of the projected cash flow over the life of the ship, including assumed inflation rates that vary with the cost components.

*Present Value of the Life Cycle Cost* is the present worth or value of the projected cash flow assuming a discount rate.

*Discount Rate* is the nominal interest rate that the owner may expect to obtain if he were to invest the same money at t=0 in an income producing venture, either in other internal company projects or in external investments. This is a highly variable number. It will vary among owners, as well as depend on prime interest rates at the time, projected profit margins for the company, and target corporate rate of return.

*Uniform Equivalent Annual Cost* is the present value of the life cycle cost distributed over the life of the ship using the same discount rate, so that each year has an equal cost. This is also known as the average annual cost (AAC).

The following assumptions were applied in the life cycle cost analysis for *Polar Endeavour*:

| | |
|---|---|
| Life of the ship | 30 years |
| Hypothetical discount rate: | 8% |

- Shipboard crew labor rate, direct and indirect $50/hr (US Yards)
- Inflation rates

| | |
|---|---|
| Fuel and Chemicals: | 3.0% |
| Labor: | 5.5% |
| UV lamps and parts: | 4.0% |

- Increased ballast pump usage was calculated as described earlier, including: the effect of non-gravitating, the increased head in the system from the CSs, a 5% increase in total pump volume required to fill the tanks due to the sludge discharge of the CS, the increase in pump maintenance and the increased fuel consumption for generating electrical power to drive the pumps.
- UV lamps have a 1000 hour life, and their material cost as well as the labor cost of replacing the lamps is included. The lamps also have a manufacturers recommended replacement interval, that occur sooner than the hour life. UV units are energized for both the ballasting and deballasting operations.
- The increased fuel consumption for generating UV unit electrical power is included.
- The cost of the chemical additive is included on a per-ton basis, assuming crew labor each trip to handle and mix the chemical.
- Polar Tankers reports they have no significant problems with the accumulation of mud in the ballast tanks of TAPS trade tankers, so there is no cost savings associated with reducing mud in the tanks.

Additional assumptions are presented in Appendix A, along with the detailed calculations of the life cycle cost.

The results of life cycle cost analysis for the *Polar Endeavour* are presented in Table 5. One cost metric is developed and illustrated in the table. Dollars per ton of ballast water treated is indicated. This is a reasonable cost comparison metric when comparing costs of different systems for a specific ship, but is not appropriate for comparing different ships. See Section 7 of this report for a discussion of cost metrics.

It should further be noted that changing the assumptions of vessel life and the owner's discount rate will have a significant impact on the results.

**Table 4. Installed Cost Data – *Polar Endeavour***

| Item | Material Cost | Labor Cost | Material Markup | Contingency | Total |
|---|---|---|---|---|---|
| 1. Main Ballast System Cyclonic Separators | $321,300 | $83,300 | $48,200 | $48,600 | $501,400 |
| 2. Main Ballast System UV Light Treatment Units | $427,000 | $181,503 | $64,100 | $73,000 | $745,600 |
| 3. Aft Ballast System Cyclonic Separators and UV Units | $473,900 | $135,190 | $71,100 | $73,100 | $1,506,293 |
| 4. Chemical Treatment | $38,000 | $22,450 | $5,700 | $7,300 | $73,500 |

**Table 5. Life Cycle Cost Data – *Polar Endeavour***

| Item | Installation Cost | Life Cycle (LC) Cost | Present Value of LC Cost | Uniform Equivalent Annual Cost (AAC) | Tons of Ballast Pumped/Year | Cost/Ton |
|---|---|---|---|---|---|---|
| Main Ballast Treatment – CS & UV | $1,247,000 | $2,444,000 | $1,614,000 | $143,000 | 1,435,200 | $0.10 |
| • CS only | $501,000 | $729,000 | $573,000 | $51,000 | 1,435,200 | $0.04 |
| • UV only | $746,000 | $1,716,000 | $1,041,000 | $92,000 | 1,435,200 | $0.06 |
| Aft Ballast Treatment – CS & UV | $753,000 | $918,000 | $803,000 | $71,000 | 1,435,200 | $0.05 |
| Sum of Main + Aft – CS & UV | $2,000,000 | $3,362,000 | $2,417,000 | $214,000 | 1,435,200 | $0.15 |
| Chemical Treatment @ $0.20/ton | $74,000 | $11,119,000 | $3,879,000 | $345,000 | 1,435,200 | $0.24 |
| Chemical Treatment @ $0.10/ton | $74,000 | $5,731,000 | $2,014,000 | $179,000 | 1,435,200 | $0.12 |

# 6. DESIGN SUMMARY – *R.J. PFEIFFER*

## 6.1 Ballast System Characteristics, Ballasting Practices and Common Port Calls

*R.J. Pfeiffer* trades on the U.S. West Coast and in Hawaii, ballasting and deballasting to maintain stability and control trim and list. Typical port calls include Long Beach, Oakland, Seattle and Honolulu. The *Pfeiffer* has a total ballast capacity of 14,300 $m^3$ as compared with the 60,000 $m^3$ of the *Polar Endeavour*, but the ballast can be loaded into 26 different tanks compared with 17 in the *Endeavour*. The *Pfeiffer* is outfitted with a separate heeling pump and two dedicated wing tanks, one port and one starboard, to adjust for adverse heel associated with unbalanced cargo loading conditions. These heeling tanks are filled with fresh water and are not used in normal ballasting operations.

The *Pfeiffer* carries ballast in the full-load condition for stability and in a partial load condition for trim. Currently, the ship's ballast system does not have the capability to transfer ballast between tanks. As a result, ballast water is discharged to the sea when tanks are deballasted even though new ballast water may be brought into other tanks to reach the desired load condition. If possible, ballast adjustments are made at sea prior to arriving, in anticipation of the expected loads, or after departing the port. Some ballasting may be necessary during container loading and unloading operations. A review of previous voyages indicates that a total of about 400 to 500 tons may be loaded in multiple ports during a typical round-trip voyage. Most ballast currently discharged in port is deep ocean water because the vessel has been successful in implementing open ocean exchange on a regular basis.

Unlike *Polar Endeavour*, *Pfeiffer* does not utilize gravity flow ballasting, and the added pump energy to overcome the added pressure losses is negligible in this size range, particularly given the smaller quantities pumped. Increase in ballasting time is only the amount to make up for the sludge discharge, which is accounted for in the life cycle costs (there is a minor amount of added fuel for the added power generation) but has no impact on the ballast operations.

## 6.2 Treatment Philosophy and Functionality

We have selected treatment systems that have demonstrated effectiveness for this study. The initial plan, based on the results from the Great Lakes testing [3, 6] was to pursue a filter system with automatic backflush as the primary treatment and a UV light unit as the secondary system. However, the cyclonic separator was chosen as the preferred primary treatment because of the mechanical simplicity of the separator as compared with the filters. The actual shipboard maintenance costs for the filters are not yet fully understood. The separator also fits better into the engine room arrangement.

Normal ballasting operations require the use of only one pump, so only one treatment system, consisting of separator and UV unit, is needed. Both the separator and the UV system are sized to the 350 $m^3$/hour (1,500 gpm) capacity. The system is designed so that ballast water flows through both the separator and the UV unit when loading ballast, but only through the UV unit at discharge.

While both options are studied, only one is intended for installation. Chemical treatment is not desired or considered at this time for this vessel.

## 6.3 Description of System Equipment

The following treatment equipment options were studied for installation in the *R.J. Pfeiffer*.

1. Cyclonic + UV (preferred):
   Primary Treatment: Cyclonic Separator, MicroKill Sep, Model SKX350
   Secondary Treatment: UV Light Treatment, MicroKill UV, Model MP300-04-2500

2. Filter + UV:
   Primary Treatment: MicroKill Filter, Model 6 x 4" with backflush unit
   Secondary Treatment: UV Light Treatment, MicroKill UV, Model MP300-04-2500

## 6.4 Equipment Installation Issues

Equipment installation on *R.J. Pfeiffer* is relatively simple compared with the *Polar Endeavour*. There are no hazardous space complications and the engine room (although not spacious) has available room for the machinery. The piping runs (10" pipe) are a bit longer than desired, but there are no significant equipment installation issues.

## 6.5 System Setup, Operation and Equipment Monitoring

Ballast operations and monitoring of the cyclonic separator and UV unit are similar to those discussed for *Polar Endeavour,* but the setup, operation and monitoring of the filter system is unique to the *R.J. Pfeiffer*.

The equipment provider has proposed that the *Pfeiffer* filtration unit be continually backflushed as required during the ballasting operation. The backflush process is begun by securing the valves on the input and output side of one filtration element. A separate backflushing pump with a hydrophore tank will be activated to backflush that element of the filtration unit. Initially that backflushing was going to be manual and later an automatic backflush system was identified. The backflush water will be collected in a separate tank and then discharged using a newly installed line to the suction side of the existing bilge/ballast eductor. The actual discharge process could be accomplished either in port or at sea after leaving port. Alternatively, the tank could be emptied automatically using a float activated switch controlling a dedicated pump and a separate discharge pipe line with a hull penetration and appropriate valving.

Particular to the *R.J. Pfeiffer*, and possibly other vessels, it will not be simple to add to the existing alarm and monitoring system. The system is a custom, one-off design that may be difficult to change. It will probably be necessary to install independent controls, alarms and monitoring for the ballast treatment system, keeping the monitoring system independent of the main ship system.

## 6.6 Sampling and Treatment Performance Monitoring

Sampling ports will be provided to sample ballast water on board to determine treatment effectiveness in a manner similar to that discussed for the *Polar Endeavour*. One inch (1") sampling ports are provided before the hydrocyclone or filter, after the hydrocyclone/before the UV, after the UV, and at the sludge discharge from the filter.

## 6.7 System Maintenance

Maintenance issues are manageable for both options. Issues of UV light intensity calibration and lamp replacement will be the same as on *Polar Endeavour*, with added maintenance imposed by the filter unit. The section on life cycle costs, below, includes the effect of maintenance on ship's crew costs.

## 6.8 Personnel Training and Safety

Training and safety issues are also manageable. See the discussion for *Polar Endeavour*.

## 6.9 Shipyard Scope of Work

The two options for treatment systems on *R.J. Pfeiffer* have separate shipyard work scopes.

**Option 1 – Cyclonic Separator w/ UV Light Treatment Unit Serving the Starboard Ballast Pump**

The ballast system piping will be modified to install the cyclonic separator as shown on the drawing, including its foundation, sludge line and new dedicated overboard discharge. Six (6) new motor operated valves will be installed.

The ballast system piping will be modified to install the UV unit as shown on the drawing, including foundation, control panel and power panel.

Electrical power (approximately 5 kW) will be fed from an auxiliary machinery power panel.

Control and monitoring wiring will interconnect the equipment to the control panel installed in the engine room and to the ballast control station in the ship's office on the main deck.

**Option 2 – Filter System with UV Light Treatment Unit Serving the Starboard Ballast Pump**

The ballast system piping will be modified to install an Arkal filter system with a separate manual backflush pump and hydrophore tank. The unit will be configured to best fit into the space, providing access to all components.

The backflush holding tank will be installed complete with level indicator signaling automatic startup of the backflush discharge pump. A dedicated overboard discharge piping line with hull valves will be installed.

Power for the solenoid valves will be fed to the unit control panel from a local 120V power panel.

## 6.10 Installation Cost Estimating Assumptions and Data

We applied the same cost estimating assumptions to *R.J. Pfeiffer* as we did to *Polar Endeavour*. A summary of the estimate is provided in Table 6.

## 6.11 Life Cycle Cost Analysis Assumptions & Data

Life cycle cost estimating methods for *R.J. Pfeiffer* are the same as for *Polar Endeavour*, but there are a few differences in the assumptions. Additional assumptions can be found with the cost details in Appendix A.

| | |
|---|---|
| - Remaining life of the ship: | 20 years |
| - Hypothetical discount rate: | 8% |
| - Shipboard crew labor rate, direct and indirect: | $50/hr |
| - Inflation rates: | |
| - Fuel: | 3% |
| - Labor: | 5.5% |
| - UV lamps and filter parts: | 4% |

- UV lamps have a 1000 hour life. Material cost, as well as the labor cost of replacing the lamps, is included.
- The increased fuel consumption for generating electrical power for the UV units is included.
- Cost savings for reduced mud in tanks is considered insignificant in the *Pfeiffer* and is not addressed.

The results of the life cycle cost analysis for *R.J. Pfeiffer* are presented in Table 7. Details used in developing the estimates are found in Appendix A.

**Table 6. Installed Cost Data – *R.J. Pfeiffer***

| Option | Material Cost | Labor Cost | Material Markup | Contingency | Total |
|---|---|---|---|---|---|
| 1. Cyclonic Separator and UV Light Treatment Unit | $199,600 | $108,700 | $29,900 | $37,000 | $375,200 |
| **OR** | | | | | |
| 2. Arkal Filter and UV Light Treatment Unit | $196,000 | $97,016 | $29,400 | $35,200 | $357,600 |

### Table 7. Life Cycle Cost Data – *R.J. Pfeiffer*

| Item | Installation Cost | Life Cycle (LC) Cost | Present Value of LC Cost | Uniform Equivalent Annual Cost (AAC) | Tons of Ballast Pumped/Year | Cost/Ton |
|---|---|---|---|---|---|---|
| Cyclonic Separator & UV Treatment | $358,000 | $483,000 | $413,000 | $42,000 | 13,000 | $3.23 |
| Filter & UV Treatment | $375,000 | $633,000 | $488,000 | $50,000 | 13,000 | $3.85 |

# 7. COST METRICS USED TO COMPARE SYSTEMS

Developing the actual costs for ballast water treatment is important not only for the ship owner as he makes a decision about which system to purchase and install, but also for the regulator considering the feasibility of treatment solutions and efficacy standards. Cost metrics are economic parameters that can be used in making comparisons among different solutions.

For ballast water treatment systems, there is no simple metric that can provide a clear-cut indication of the most cost-effective solution across all ships; however there are a variety of cost metrics that can be used depending on the specifics of the comparison. The following table summarizes the cost metrics proposed for use in evaluating ballast water treatment system installations, with a detailed description of the metric following the table.

| **To compare treatment system costs -** | **use -** | **to calculate -** |
|---|---|---|
| for a specific vessel | Present Value (PV) and Average Annual Cost (AAC) | $/ton of ballast water treated |
| among vessels of the same type and service, but different sizes | Change in Required Freight Rate (δRFR) | $/ton of cargo |
| among different ship types | AAC and Annual Operating Cost | Percent increase in annual operating cost (or increase in Charter Rate) |

## 7.1 Cost per ton of ballast treated ($/ton)

Cost per ton of water treated could be the PV divided by total ballast treated over the defined life of the ship, or the ACC divided by the average annual ballast treated. Both of these metrics are quite easy to determine but can vary widely for different ship types even when the same treatment system is used. Ships that process large quantities of ballast water can have a low $/LT figure while ships which need only treat small amounts of ballast water can show a very high $/LT. There is no way to judge the impact of these costs on the earning capability of the ship or relative increase in operating costs. For a simple comparison of systems for a given ship, however, this is a reasonable metric.

## 7.2 Change in Required Freight Rate (δRFR)

The required freight rate (RFR) measures what the ship must charge per LT of cargo to earn a specified return. It is calculated as the average annual costs / annual cargo dwt. Determining the change in RFR due to added costs of a treatment system would reflect how those added costs reduce the earning potential or value of a vessel to its owner. Or, if the market will absorb the change in freight rate, how much that rate must increase to cover the costs of the ballast water treatment in a specified period of time (the payback period). This is independent of how much ballast water is carried and treated.

The change in RFR is most useful if reported as a percentage of the actual RFR. This requires the calculation of the ship's total average annual costs as well as the cargo deadweight carried.

However, projecting cargo deadweight is not always precise. For a tanker or bulker on a regular run it can be straightforward. For less regular services (ships on the spot market), for ships that regularly sail with less than full deadweight, or ships that typically consider RFR based on piece counts and not deadweight (such as containerships which look at $/TEU) establishing a fair cargo deadweight is not straightforward. It will involve assumptions that are difficult to make and apply consistently for ships of different types.

The change in RFR as a percentage of total RFR can be quite useful for ships of a similar type but different size. But, it still may not be a reliable comparative measure for ships of different types.

## 7.3 Change in Average Annual Operating Cost

Average annual cost of the treatment system divided by the total annual operating budget of the ship (percentage change in operating costs) would allow an assessment of the percentage increase in costs due to installation and operation of the treatment system. Like the RFR figure, this metric tries to connect the treatment system costs to the vessel's value and not to the amount of ballast water treated. It is perhaps more useful than the change in RFR figure for ships of different types because it removes the cargo deadweight and actual RFR from the calculation. For vessels that operate under charter agreements, this metric can be used to determine a change in the vessel's charter rate. A charter rate is independent of cargo deadweight and is derived directly from vessel operating costs.

For quick assessments and comparisons, worldwide benchmarks for operating costs could be used. These include world scale pricing for tankers or short-term charter day rates for other vessels. These rates naturally fluctuate with market demand, but if the rates are clearly stated, any results could easily be adjusted.

## 7.4 Life Cycle Cost Estimating Assumptions and Standards

It is essential that all costs (and economic benefits) be identified in the estimates, and that assumptions for life cycle estimates be consistent.

When considering any treatment system, the following cost parameters should be included:

1) Initial equipment purchase (including tax, shipping, vendor markup, etc.
2) Full installation cost
    - indicate where work to be done, labor rate and currency
    - include related system modifications for equipment installation (piping, valves, controls, electrical hookup, etc.)

- include drydocking and tank cleaning (if required), and schedule disruption
- include upgrades of related equipment if necessary to maintain flow rates/volumes (ballast pumps, etc.)

3) Operating costs
    - regular maintenance (labor and spares)
    - additional crew labor for new procedures
    - additional power consumption of new equipment and existing equipment running longer
    - increased maintenance of pumps and related systems operating longer or under greater load
4) Savings from ballast exchange no longer carried out and changes in port fees and reporting requirements
5) Savings from reduced sediment build-up in tanks and associated cleaning costs
6) Savings/costs from changes in available cargo deadweight due to treatment equipment weight and/or reduced tank sediments
7) Disruptions in ship schedule do to longer ballasting times
8) Engineering and contingencies

For Life Cycle Cost analysis, the following should be clearly identified:

1) Ship or system life
2) Discount rate
3) Inflation rate
4) One time and recurring costs
5) PV of cash flows, and PV/initial investment
6) AAC (average annual cost of all cash flows)

## 7.5 Cost Metric Conclusions

For a specific ship whose owner is trying to determine the most cost effective ballast water treatment solution, a $/ton ballast water treated is a reasonable metric.

For ships of a similar type in a similar trade, the change in RFR metric is quite useful in assessing the true economic impact of ballast water treatment. It also should work well for ships of different sizes but similar types. The change in RFR metric, however, does not work when comparing radically different ships in different trades. It suffers from the vagaries of deadweight information and actual RFR figures, and market conditions can fluctuate wildly among the different trades. What is an acceptable change in RFR for a tanker carrying crude oil may not be viable for a small coastal containership.

The percentage change in operating costs is probably the best metric for comparing different ship types operating in different services. It is still not ideal, and may not be specific enough to make decisions, but gives a good overview of the magnitude of the economic impact of ballast water treatment.

Since the treatment solutions developed and optimized for specific ship types may vary in method and cost regime, it may not even be useful to try to compare simple cost metrics across ship types. When evaluating potential treatment standards, the question of whether the standard can be achieved in an economically viable manner is more properly addressed to ship types (and service) independently. Changes in RFR, for example, must be judged in the framework of the ship's trade and market forces and not comparatively with ships of a different type.

# 8. ABS REVIEW COMMENTS

The contract drawings for all options for both vessels were submitted to ABS for review and approval. The system designs represented on the submitted drawings were engineered to meet ABS requirements, and there were generally no comments. The correspondence is provided in Appendix B. In both cases, ABS was requested to perform review on behalf of the U.S. Coast Guard.

## 8.1 *Polar Endeavour* Comments and Clarifications

There were no significant comments on the submitted drawings (comment sheet in Appendix B), but there were specific questions or clarifications that were asked of ABS. The questions and responses are provided below.

**Clarification #1**

ABS Rule 5-1-7/31.9 states that electrical equipment is not to be installed in hazardous areas unless essential for operation purposes. Can the U/V unit be considered essential for operation purposes, assuming the following safeguards are in place?

1. The unit will hold explosion proof certification.
2. All control of the unit will be from outside the pump room space. There will be no local controllers.
3. The unit will have three independent interlocks:

a) The unit's power supply will be interlocked with a flow switch in the ballast piping, so that it cannot be energized unless there is water flow in the piping. A time delay will be incorporated with this interlock, so that a few seconds of flow will exist before the unit is energized.
b) The unit's power supply will interlocked with the pump room ventilation fans.
    c) The unit casing will be pressurized with an inert gas (such as nitrogen), and an intrinsically safe pressure sensor will also interlock with the unit's power supply. The internal pressure will keep the pump room air from infiltrating the unit.

**Clarification #2**

Although the arrangement of the UV compartment (Figure 6) isolates the UV unit from the pump room, when the access plate in the engine room is removed for maintenance, the ballast water piping could then be considered to enter the machinery space, violating 5-1-7/1.7.2 and 5-1-7/5.3.2(b). Can this be considered an acceptable arrangement?

*ABS responded no, that this is an un-acceptable arrangement.*

**Clarification #3**

ABS responded that there are no regulatory requirement or problems with the stowage of biocides on board the vessel.

**Clarification #4**

ABS responded that there are no specific equipment approval requirements for the cyclonic separator, but that they do not accept DNV certification as being acceptable to ABS.

## 8.2 *R.J. Pfeiffer* Comments

As with the Endeavour, there were no significant comments on the submitted drawings (comment sheet in Appendix B), and only one clarification requested.

**Clarification #1**

Are there any equipment approvals required for the treatment components: the cyclonic separator and UV unit?

*ABS responded that there were no specific requirements.* Subsequently, the vessel owner raised questions about the equipment that have been addressed, with the U/V unit for Pfeiffer specifically approved by ABS for installation.

# 9. CURRENT STATUS

## 9.1 *Polar Endeavour* Installation

Given the technical challenges associated with the installation of the UV unit and the cyclonic separator, Polar Tankers is investigating further the use of biocide to treat their ballast water. They are currently in the process of planning tests, and are actively addressing the issue of ballast water treatment on these tankers.

## 9.2 *R.J. Pfeiffer* Installation

Matson Navigation has proceeded with the installation of a CS and UV on board *R.J. Pfeiffer*. They selected the CS unit over the filter units because of they perceived significant maintenance issues with the filter units. These maintenance issues are reflected in the life-cycle cost data, and bear out with increased cost.

Matson is planning to conduct a testing program with analysis carried out by Moss Landing Marine Laboratories.

# 10. CONCLUSIONS

Ballast water treatment technologies are advancing beyond the scientific investigation stage to the engineering stage, where potential ship systems can be evaluated, designed and installed. Nonetheless, continued scientific bench testing and additional full-scale testing of treatment solutions are needed.

This report presents full-scale installation studies, and at least one of the studies is becoming a reality with the installation of a system on board. It is hoped that this actual installation experience will validate the efficacy estimates and the cost modeling.

Consistent methods of cost analysis are also important to properly assess the treatment systems. The present value of $/ton of ballast pumped over the life of the ship is one measure of economic merit that sounds simple, as does increase in required freight rate. However, these measures are difficult to use across various ship types. The percentage increase in operating cost may prove to be an effective cost metric for comparison across ship types. Methods of evaluating treatment system cost must be specific to each type of vessel (volume of ballast handled varies), to each individual ship within a type (remaining ship life varies) and to each owner (economic models vary).

Selection of equipment and the associated treatment method will be based not only on life cycle cost, but also on simplicity of changes and owner preferences and judgment. Elements of the system installation design and equipment selection processes will vary from ship to ship, and from Owner to Owner.

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# ACKNOWLEDGEMENTS

The Great Lakes Ballast Demonstration Project has made another important step in addressing the problems associated with the introduction of nonindigenous species into marine ecosystems. The marine engineering represented in this paper addresses two ships or ship classes. More importantly, two major U.S. ship owners participated in the process, and they are much closer to getting viable ballast treatment systems installed in ships.

Polar Tankers, Inc., and Matson Navigation Company are acknowledged for their input, enthusiasm and support for this project.

The American Bureau of Shipping graciously agreed to provide regulatory guidance and input to this study without charge. Their efforts and support are greatly appreciated.